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THE DEEPER AND THE RICHER MEANINGS OF MATHEMATICAL TEACHING IN ELEMENTARY SCHOOLS

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MODERN THOUGHT AND TENDENCIES FAVORABLE TO MATHEMATICAL EDUCATION

This is an age of industrial and economic standards. To bewail the spirit of the time as commercialism is as futile as it is unprogressive. Earnest and prudent men do not deny facts; but accept them and deal with them. Hence, educationists are attempting to put their theories into efficient relation with economic and industrial facts. Attempts to harmonize the grounds of education with the basal facts of modern industrial conditions are being integrated into the doctrine of pragmatism. Speaking roughly and roundly, this doctrine seems to mean that truth is that which works well, frees activity, liberates thinking. Utility, broadly conceived as workability, is at the bottom of it. When educational theory veers into this course, mathematics in school work readily finds for itself both fulcrum and purchase.

The watchword of industrial enterprise is the utilization of waste products. The extent to which waste products are being converted into by-products marks the present epoch. The observance or non-observance of this law of conversion makes most of the difference between industrial successes and failures. Thus industrial survival is spelled out in terms of the closeness with which raw material balances output, with which means balance ends. Wherever accuracy of adjustment of means to ends, economic balance of effort and result, are called for, there is the place and function of mathematics. In this domain mathematics comes to its birthright, and enters pre-eminently into its own.

Consequently, whether viewed from the vantage-point of the educational theorist, or of the man of affairs, the mathematical element in education is peculiarly opportune and efficacious in the work of modern society and of social progress. But that mathematics may perform its proper office richly and liberally in educational polity, its deeper meanings must be seized and pressed into practical service. The principle of action, referred to above, that has been so well wrought out in the economic world, is freighted with significance and suggestion for the thoughtful teacher of elementary-school mathematics. This very wholesome practical doctrine has not yet been worked into the teaching of elementary-school mathematics with much thoroughness. Too large a percentage of pedagogic effort in arithmetic is devoted to mere mechanical training; and too small a proportion to educating. There are too many waste products in current processes of teaching arithmetic. No school subject, old or new, offers to well-qualified professional ability wider scope, richer opportunity, or brighter promise for improvement of output, by a completer observance of this economic law of conversion, than does school arithmetic. Lest the power of the combined evidence from educational philosophy and from practical economics fail of convincing some on this point, evidence from classroom experience may also be admitted.

MATHEMATIZED ARITHMETIC

My reason for preferring the term, elementary-school mathematics, to the customary term, arithmetic, is that the scope of the mathematical work of the modern elementary school is much broader than arithmetic, in a definitive sense. It includes form-study from the first grade through the eighth grade. It also includes the first notions of algebra under the form of general arithmetic. The form-work ripens gradually into the rudiments of geometry, before mensuration is completed. This work is all unified around an arithmetical center, and taken up at such times and places as to illuminate, to rationalize, and to reinforce the arithmetic—not primarily to prepare for high-school mathematics. In a phrase, the proper subject-matter for elementary-school mathematics may be fittingly termed *mathematized arithmetic.* It is this type of mathematical work that I have in mind, whether I use the phrase elementary-school mathematics or simply arithmetic.

DEEPER AND RICHER VALUES OF ELEMENTARY-SCHOOL MATHEMATICS

The deeper and richer meanings of elementary-school mathematics, whose importance in teaching I wish to emphasize, are:

1. Clear imaging and clear thinking.
2. Connected thinking and inference-making.
3. Concentrated thinking.
4. Independent thinking and judging.
5. Exercising the power to choose and strengthening the will.

These several virtues of mathematical work are enumerated in the order in which they should be emphasized in teaching.

In the first and second grades of many elementary schools, the arithmetical work that is done is made incidental and contributory to other school activities and subjects. No special attention is given to the number- and form-interests of children. Still the other school arts of reading and writing are begun explicitly at once. Neither the *laissez-faire* nor the occasional type of treatment is held to be good for the school arts of reading and writing in the first and second grades. For them it is conceded that a good beginning is half the battle. To me it seems a grievous error to withhold expert aid from the beginner in arithmetic as long as is customary. This is the very subject in which a poor start, or a wrong start, after working great havoc to interest and profit in school work, turns more boys and girls away from the schools, than is the case with any other school subject. The distaste that children manifest toward arithmetic is due, not to the subject-matter, but to a wrong start, or to no start at all, aggravated by poor subsequent teaching of the subject. It is the teaching, or rather the lack of it, that is the rock of offense. Boys and girls should no more be denied the opportunity of a fair start in arithmetic on the ground that they cannot do the work well, than they are denied the opportunity of getting started right in reading and writing, because at first they cannot read or write well.

THE TEACHER'S MOTIVE SHOULD BE CLEAR

But whether the programme provide help for the children at the outset or not, it is important that the teacher have clear ideas and convictions as to the phases of number- and form-work that should receive attention during the first and second school years. Even under the plan of incidental number-teaching, the teacher may render efficient service as occasion permits, by stopping now and then to stress, or to solidify a little, a number- or form-notion met in the other work. It is even more important that this be done frequently under the incidental plan, than under the plan of explicit teaching. For children of this period are greedy for sensations about everything. Many of these sensations must pertain to number, form, and magnitude. Soon this greed for sensations results in a large mass of nuclei, or cores of concepts and images. If no aid is at hand in ordering and systematizing a little this mass of material as it accumulates, it remains an unassimilable mass of detail of little use to him who has it. Indeed it often becomes a source of general confusion of mind to him. Soon this confusion becomes more confounded by the rapidly accumulating materials of sensation, and the pupil grows perplexed and annoyed. If help be withheld at these critical moments pleasure in future arithmetical progress is doomed. All this I have so often seen, both in the classroom and outside of it, that I cannot be either mistaken or exaggerating.

PURPOSE OF SECOND-GRADE WORK TO DEFINE AND CLARIFY IDEAS OF QUANTITY

In the second school year the supply of more or less poorly defined ideas becomes unwieldy. It is imperative that some defining and clarifying of these ideas be done. The notions, started through the seeing, handling, playing, and working with things in the first grade, must be given some fulness and definiteness of outline. This is done through the "how much?" and "how many?" of number and magnitude. The distinctive purpose of the second-grade number-work should be delimiting and clarifying quantitative imagery. Simple estimates, indefinite comparison of magnitudes, and the beginnings of definite comparisons and measurements should be salient features of this year's work.

The activities and materials through which the image cores of number and magnitude should be set up are: rhythmic movements, skipping plays, singing, number, rhymes, playing store, dramatic plays, committee work, making, cooking, cutting, gardening, sewing, drawing, estimating, comparing, measuring, counting rhythmically (by 2's, 5's, 10's, etc.), intuitive geometry, the number names, the digits, quick work, reading foot-rule, thermometer, and recording facts found in number dictionaries.

FORMAL WORK FOR SECOND-GRADE ARITHMETIC

The formal work of the second grade should include, at frequent intervals, such oral exercises as: "Give some numbers that, together, make 12, 14, 15," etc. Call for volunteers rapidly; write down the numbers as given, and have the class, sometimes as a whole and sometimes one at a time, add up the suggested numbers, to convince all that the numbers, taken together, do make the required number. This helps the pupil to feel the essential nature of adding, and moreover it has the psychological warrant of keeping the pupil working within a more or less vague whole to define it more fully.

Addition is thus used as a way of making vague wholes definite, as a kind of measurement. There is purpose in it for the pupil. It helps him to know some things better. Some pupil will say, directly, that 14 is a 10 and a 4. Then stop, with some such casual remark as: "Why certainly. One might see that by looking at it." Continue with enough such work to make clear the place-value of digits in two-figure numbers.

The learner thus comes first to an unknown number, as 18, *as a whole,* that he knows little about, but feels he ought to know more about. He breaks it into parts, learns it through these parts, which never get so far from the whole that the learner loses connection of whole and part. He always and continually looks at 18 in the light of its parts. This is just the opposite of the customary procedure of constructing numbers by heaping unity upon unity with the learner blindfolded as to the goal of the heaping, until the very end, when the number the teacher had in mind is reached. Under the suggested plan the constructive steps are taken in the full light of their bearing on the number, as 18, that is being learned. Then, as soon as the pupil sees that 18 is

10 and 8, ask: How many is 18 less 10? 18 less 8? thus bringing out and impressing, at once, the related character of addition and subtraction. It is wasteful in the extreme, not to teach addition and subtraction together, for ideas then have to be acquired by bits and by piecemeal. The *fragment* of an idea is difficult to acquire and next to impossible to retain.

Next, "Give some numbers that, combined, make 21, 23, 24," etc. Call for volunteers, as before. When someone says for 21, 10, and 11, stop, remarking casually: "That's what I wanted, 1 ten and 11 ones." Then treat 22, 23, etc., similarly, emphasizing as the thing you wanted, the 1, 10, and 12 ones, 1, 10, and 13 ones, etc. The bright boy will catch the point quickly; but allow the slower ones to do most of the answering, until many can at once see a two-figure number as so many tens and 11, 12, 13, 14, etc. Do not hurry the work. Give more than one day to it. This not only teaches addition at its best, but also gets ready for subtraction without the carrying and borrowing vernacular. Such work should be a feature of second-grade arithmetic. Pupils enjoy it, and so will teachers, particularly when the fruits of clear thinking and imaging begin to show. If you are skeptical about it, try it until you acquire a modicum of skill at it, and you will never return to the interest-killing unity-heaping to build numbers.

After such exercises as the foregoing, the pupil will lay hold at once of such work as: "Take 17 from 43;" thus, 7 cannot be taken from 3; but 43 is 3 tens and 13 ones; 7 from 13 leaves 6, and 1 ten from 3 tens leaves 2 tens; 2 tens and 6 ones, 26 ones. But he soon does it all more quickly than we can say it.

As 12, 14, 16, etc., are being broken into parts, ask: "Who can give 2 *equal* numbers that make 12, 14, etc.?" Then: "What number is ½ of 12, 14, 16, etc.?" Directly ask: "Who can give 3 *equal* numbers that make 12, 15, 18, etc.?" Follow at once with: "What is ⅓ of 12, 15, 18, etc.? ⅔ of 12, 15, 18, etc.?" This work suffices to show that there is an abundance of easy formal number-work adapted to second-grade immaturity, that would very materially assist in clear imaging, and would lay the foundation safe, sure, and speedy, for pleasurable and profitable progress later. For fuller work of second-grade difficulty, see also Myers-Brooks, *Elementary Arithmetic,* Part I.

THE TIMES-IDEA AND THE TABLES

The next difficulty on the road to learning arithmetic is multiplication with its inverse operation, division. Both the times-idea and the multiplication tables should be very thoroughly and rationally taught. I am opposed to drilling, or attempting to drill these matters into children. I do not agree that learning the multiplication tables is a grim struggle of pure memory, the rigors of which can in no wise be mitigated. I am confident that the teachers of this state who give the Myers-Brooks *Elementary Arithmetic* a fair trial will agree with me before two years, if they do not now agree, that learning the tables is one of the most interesting as well as one of the most illuminating parts of arithmetic. This book first teaches, and teaches thoroughly, the tables. Then it drills amply upon them.

The most helpful pedagogic means of teaching the tables is measurement. This is not because measurement is numbering; but rather because the physical acts that must be gone through in measuring run so closely parallel to the mental steps that must be taken in numbering, that all the motor imagery of the former serves to reinforce and to guarantee the correct mental imagery of the latter. The cyclic acts of putting down, taking up, noting the end-point; again putting down, taking up, and noting the end-point, doing it again, etc., until the magnitude in question is measured, are so rhythmical, so repetitive, as to suggest inescapably the rhythmical balancing of the parts in a whole, which is the essence of the times-idea. The multiplicand is so clearly the standard of measurement, the multiplier, so clearly the number of times the standard is to be used, to be put down and taken up to give the product, that multiplication must, perforce, be sensed by the learner as a kind of actual, or imagined, measurement.

TEACHING THE MULTIPLICATION TABLE

Teaching the tables rationally includes (1) a reconnoiter of each part of the table; (2) constructing the table diagrammatically, as with squares, or on squared-paper; (3) building the tables additively; (4) a first attempt at committing the tables, during which most, not all, of the committing will be done; (5) drill upon the tables, not once for all, but pretty copiously, at this stage, and then systematically for a brief time every day or two; and (6) applying the tables in problems.

In reconnoitering the part of the table being taught, the common denominate number standards that are related to the particular table in question should be used in easy problems that can be solved and understood, *by common-sense methods without the table.* This impresses the pupil with the true reason for learning the tables; viz., because they are constantly needed in common measurement. Only purposive teaching *educates;* mechanical teaching, at best, only *trains.* For example, in the 3's, 3 ft.=1 yd.; in the 4's, 4 qt.=1 gal., and 4 pk.=1 bu., and the like can be made to do valuable service, while, incidentally, most of the basal denominate number facts are taught, and much better taught, than in the old-time isolated, topical fashion. The knowledge of these facts, thus acquired, becomes a more thoroughly organic possession of pupils than the compartmental treatment makes them.

In building the tables, such facts as the following should be closely associated: $5\times6=30$; $6\times5=30$; $1/5$ of $30=6$; $1/6$ of $30=5$; $30\div6=5$; $30\div5=6$; what are the factors of 30? and such variations as: 6 5's=how many 6's? 4 7's=how many 4's? etc.; and 7 15's=how many 7's? 8 25's=how many 8's? etc.; 2 3's are 6; how many 3's in 2 6's? in 3 6's? in 5 6's? etc.; 3 6's are 18; how many 6's are 2 18's? 3 18's? 4 18's? and so on through the 6-series of products; then the 8-series; 10-series; 12-series; etc.; ¼ of 40 is 10: how many fourths of 40 is 20? 30?

Obviously, the possibilities of such work as this are unlimited. Five to ten minutes a day ought to be given to it from the third grade through the eighth. Time forbids further specifications of detail on this point; but perhaps enough has been said to make my point, that clear thinking and clear perceiving will be the sure outcome of good arithmetic teaching. It may be added that the great value of this type of formal work as training in concentrated and ready thinking, in mental springiness, and mechanical freedom, are among its virtues. The work must be brisk, and snap, and there must be movement and purpose to secure concentration of attention and thought. It is better to step aside from the main line of work for three to five minutes when a number difficulty is met that drill will relieve, and give the necessary drill, then pass on, than to take a whole class period for drill. No one will admit this more readily than the real teacher.

Factoring, cancellation, and checking work by casting out the nines and by other familiar processes are of great assistance in readiness and concentration of thought if these processes are not taught as separate topics for their own sake, but as matters to be used on every proper opportunity, to shorten, to facilitate, and to guarantee work.

To complete the view of the scope of the grade work as a whole we must continue a little farther.

PURPOSE OF THIRD- AND FOURTH-GRADE ARITHMETIC

The specific arithmetic duty of the third and fourth grades is to get the bulk of the tabular machinery of arithmetic under easy working control *through teaching and using* this machinery on easy problems drawn partly from the natural situations of life and partly from set lists designed to impress the particular lesson in hand.

The broader educational purpose of this period of the curriculum is to get started well the study of number and magnitude relations and connection. The beginnings and some progress in connected thinking must here be a part of the teacher's set purpose. The rational mastery of the multiplication table has this specific educational meaning and office.

FIFTH- AND SIXTH-GRADE ARITHMETIC

The fifth and sixth grades must seek especially to extend the learner's control of the four laws of addition, subtraction, multiplication, and division to fractional number, both common and decimal. The broader educational aim here is to give some measure of control of connected thinking, inference-making, and practice in choice of means that are best suited to meet clearly defined ends. Pedagogical effort should here be directed particularly to work calculated to strengthen judgment, to encourage independence, and to confer the feeling of power actually possessed. The feeling of joy in achievement here rises to a veritable craving.

Problems must now require for their solution more than one process, and oftentimes all four of the processes, that the pupil may learn to select the appropriate process for the work, i. e., that he may be trained specifically in *when* to add, when to subtract, to multiply, or to divide, and to prove independently whether his decisions are correct. If his decision be found incorrect, he should be required himself to correct it. In my opinion, no set answers should be allowed in the classroom here. Answer books, made necessary by the demands of teachers and school officials—even correct answers—are serious obstacles in the way of independent thinking. May the time speedily come when the current tendency to cut out the obsolete and the useless and the bad may be applied to the answer pages.

THE SEVENTH- AND EIGHTH-GRADE GROUND

The new ground remaining for the seventh and eighth grades to cover is percentage and interest, and their modern applications, and mensuration. In the first of these topics the only duty of the pupil is to learn a few technical business terms and to recognize when to add, subtract, multiply, and divide, and perhaps, if the teaching is good, to learn a little of the business settings of these topics. Obsolete business topics should be excluded. As the best arithmetics are presenting the subject today, by the time the pupil reaches the seventh grade he has learned nearly all of mensuration in the study of preceding topics. It only remains in the eighth grade to systematize what has already been learned. But the most important office of these two grades is to summarize and to digest into a sort of applied science the whole of arithmetic, hitherto covered. This should be done through the agency of rationalized mensuration, on the one hand, and of generalized number on the other. The rudiments of algebra and geometry should be associated with cognate phases of arithmetic all along. Such informal questions as

2 x's $=6$, or 8, or 12, etc.; what is one x?
$\frac{1}{2}x=2$, or 3, or 5, etc.; what is x?
$8+x=10$; what is x?
$7-x=4$; what is x?
$\frac{x}{4}=3$; what is x?
$ab=12$; $a=3$; what is b?
A rectangle is 3 in. high and x inches long; what is the area?
$\frac{1}{2}\pm\frac{1}{3}=\frac{3\pm2}{2\times3}$ etc., leading to $\frac{1}{a}\pm\frac{1}{b}=\frac{b\pm a}{a\times b}$, etc.

are all easy and enjoyable to children, and make them neighborly with the laws of numbers.

GOOD ARITHMETIC TEACHING TRAINS TO INDEPENDENCE

Well-taught elementary-school mathematics is peculiarly well adapted to strengthening the judgment. No other school subject, old or new, can surpass it in this regard. This strengthening and steadying of judgment is accomplished in three distinct ways: (1) in setting before pupils definite standards of judging, that are unequivocal, unbiased, and highly trustworthy, without being too difficult for the child's powers of comprehension; (2) by continually calling for and insisting upon the independent proving of work and the exercise of self-reliance in the class work; and (3) by developing a conscious feeling of growing power and independence.

To secure the virtues of independent judgment in arithmetic there must be no reasoning from authority, from precedent, and least of all must there be any of the so-called substantiating of conclusions on the basis of memorized rules. No school subject so completely repudiates all semblance of authority, of precedent, and custom, as does mathematics. It is *the* school subject which, in a pre-eminent degree, demands clear reasons and cogent proof for conclusions. The learner must not, at the peril of the best that arithmetic contains for him, be allowed to rely for assurance of the correctness of his work either upon the teacher or upon the answers of a text. No mere working for answers, no arithmetical target-shooting, no hit-and-miss figuring and spotted thinking, and no guessing at the answer, can ever allow arithmetic teaching to come to its own kingdom in education. Steadiness and certainty of mental movement, confidence and dependability of verified results, are the very spirit and essence of arithmetic work. To miss these things in teaching it is to impoverish the subject immeasurably.

Consequently, the pupil must be taught methods of checking work, must be given different ways of arriving at the same result, must be required *habitually* to use these means of backing up results. It is not sufficient, either in school or out of school, to argue: "This is the way to solve this sort of problem: I did it this way, and did it carefully; my result must be correct." To err is human—not simply childish. It is human nature also to make the same error a second time, once it has been made, if the steps are gone over in the same way. Doing the work over again in exactly the same way, merely repeating the work, may ingrain bad habits and propensities and is so poor a guarantee of correctness as to amount practically to no guarantee at all. It is essential that the order of thought be changed, by obtaining the result in another way, or by checking by some wholly independent procedure. Only thus can we hope to develop that type of arithmetical knowledge "that knows that it knows"—the knowledge that predisposes its possessor to defend conclusions, when their reliability is challenged. And this disposition to defend one's findings must be encouraged as incipient tenacity of purpose, which is an index of the seriousness with which the pupil regards his arithmetic, rather than frowned upon as incipient pugnacity. It is the groundwork of that dogged persistence in the face of difficulties which counts at par in the world of affairs. Good arithmetic can do much to foster it.

But a *little* testing and checking will not suffice. The practice must become habitual with the pupil. When school work seeks to influence conduct, it must recognize the difference to be wide between intellectual recognition and assent and that power of automatic control, which is a function of the spinal cord rather than the brain.

To illustrate: the arithmetic pupil must be taught the way, then trained into the habit, of proving sums correct by adding first upward; then downward; or by adding the columns in parts; then as a whole; then comparing the results by the different processes, or by checking the results of addition by casting out the nines. Comparing sums obtained in the usual way with those obtained by adding first the 10's, then the units, is also recommended when there are only two-figure numbers to be added. Much practice in obtaining sums orally is also urged; thus, for 47 and 35, say 47 and 30, 77; and 5, are 82. Analogous considerations hold good for the other three fundamental operations.

Factoring, than which there is no more illuminating subject in all arithmetic, seems rapidly becoming a lost art in the elementary school. This is unfortunate. It is a reflection upon the teaching, coming perilously near a disgrace, to see pupils who have found the lowest common multiple by the prime-factor process, actually dividing each number into the lowest common multiple to find how many times the lowest common multiple contains it; yet this is a common phenomenon even with eighth-grade pupils. Such work is wooden, and the teaching that is responsible for it is open to severe censure.

Another practicable and effective plan of fostering independence in the pupil, that deserves systematic employment, is that of giving time—even a full recitation now and then—for explicit training in "looking ahead before leaping." When a page of problems that call for several processes is reached, individual pupils should be called upon to read a problem through, orally or silently; to take reasonable time to see what the problem means—there should be business-like dispatch, but no hurrying here—and then to state, each in his own words, how he would solve it. The rest of the class should be attending to the explanation to correct any errors in its substance. The line should not be drawn too closely on the elegance of the pupil's English, though gross errors should be quickly corrected, but not dwelt upon. The first problem disposed of, without stopping to solve it pass to the next, and so on in sufficiently rapid succession to prevent the work from dragging. Let it be rapid-fire work; keep the class a little at a loss to know "where the lightning may strike next." When a particular problem has been solved in thought, if it is not too difficult, have the solver tell also *about what the result must be.* The list of problems may then be assigned for home work, the actual solutions to be brought to class next day, or the problems may well be solved in class next day. This plan is commended as a practicable way to teach pupils *how to study.*

The following are some of the ways in which this sort of work is of explicit benefit to the learner:

1. It resolves most of the difficulty of getting the pupil to see how he may know what to do first; what next; etc. It shows him how to clear the ground for work. It reduces that biting the pencil and not knowing "whether to multiply, or to divide."
2. There is less figuring against time, or to fill the board.
3. It teaches the economy of time and effort in getting clear as to what is to be done, before setting about the doing.
4. Pupils come to sense more keenly what it is that the arithmetical processes actually do.
5. The school work helps them directly in ways of getting ideas themselves from the printed page; i. e., in how to study from books.
6. Pupils form the habit of estimating and judging closely what results must be. In decimals, there will be little of that headless not knowing where to put the point.
7. Pupils become habituated to the correct way of attacking the problems of daily life. On such problems close antecedent estimates are required, first of all.
8. Such work appeals directly first to the understanding, then to the memory.
9. Gives incidental training in the type of good English, that undertakes to say just what it means, knows when it has said it, and then stops talking.
10. Furnishes good training in knowing what you know, when you want it, i. e., in "spot-cash business." This means concentration of thought, at its best.

Every one of these phases of benefit is seen to contribute directly and materially to the learner's ability to rely on himself—to train him into the habit of self-reliance. In cases of difficulty or perplexity he calls to his help his own fund of good judgment and common-sense. He who contends that elementary mathematics is so highly perfected in purely mechanical ways as to furnish no training in judgment, but rather to replace judgment by mechanical and automatic conclusions merely, is woefully wrong as to its teaching possibilities at least.

[NOTE.—The author will continue his discussion of this subject in the March issue of this *Journal,* treating the topics: "Good Arithmetic Teaching," "A Training in Choice," "Speed and Accuracy," and "Drill Work in Arithmetic."—ED.]